Using "The Organism" as a Conceptual Focus in an Introductory Biology Course

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A key role of introductory biology in the college curriculum (similar to other introductory sciences) is to provide students with a foundation of information on which they can build the rest of their major. Too often, however, students (and some faculty) view the introductory course as nothing more than an overview of essential facts and concepts. This "baseline" approach to teaching introductory biology is lamentable because it misses a unique opportunity to engage the students' imagination early in their college careers and, in so doing, to teach them that biology is more than just a collection of facts. Most students who enroll in introductory biology are just beginning to explore their interests in more depth than was possible during secondary school, making the introductory course an ideal venue for expanding their outlook and developing their critical thinking skills; that is, improving the students' ability to ask good questions and to know how to answer them. In our renovation of the introductory biology program at Duke University, we developed an integrated series of exercises focused on "the organism" that serve both as a way to nurture student imagination and individual interests and also as a way to teach students about the process of asking and answering questions in biology.

We chose "the organism" as a conceptual focus for this series of exercises for several reasons. First, organisms are tangible. Many students are attracted to biology initially because of an interest in organisms (fostered, perhaps, by their exposure to the abundance of nature programs on television if not their own experiences in nature). Even students who are not nature-lovers bring an intuitive feel for organisms to class. Thus, organisms provide a good starting point for grounding a student's interests in biology. This point is supported by the growing number of introductory biology curricula that emphasize the integrative and process-oriented nature of biology, as opposed to the more traditional approach of starting with chemistry and working up (Goodwin et al. 1991; Chiras 1992; Ebert-May et al. 1997; Groh et al. 1997).

A second reason is that organisms represent a particularly important level in the hierarchy of biological organization. While evolution occurs on the level of populations, natural selection acts on organisms because, in general, this is the level at which differential reproduction occurs. To the extent that most of the biological processes studied in introductory biology are in some sense or another adaptations resulting from natural selection, including phenomena occurring at the level of molecules through the level of ecosystems, these processes are best understood in the context of the organisms within or among which they occur.

We designed this exercise to stimulate student interest in biology while helping students learn scientific methods. Recent curriculum reform recommendations emphasize the importance of actively involving students as a way to engage students in biology (Project Kaleidoscope 1991; BSCS 1993; NRC 1996, 1997; NSF 1996). Especially useful activities include problem-driven exercises that require student creativity in order to achieve the specified goals (Project Kaleidoscope 1991; Chiras 1992; NRC 1996). In our project, students choose an organism at the beginning of the semester and this organism becomes their own personal focus for a series of exercises throughout the semester (as described below).

One key to the success of any exercise, however, is providing enough guidance to students so they do not feel lost on an assignment, while leaving them room for creativity in pursuing their goals. Therefore, instead of simply letting the students loose on the project, we meet with students in groups to ensure that they make adequate progress throughout the semester. We do provide feedback to the students, but we do not tell them exactly how to proceed through each step of the project. In addition, we provide students with handouts that have suggestions and guidelines for the exercise [copies of these handouts are available from the corresponding author, WJH].

"The organism" project gradually builds across the semester, starting first with students asking questions about their organism, then developing testable

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hypotheses and designing experimental tests focused on their organism (Table 1). The project culminates with each student preparing and delivering a 12-minute oral presentation in which he/she describes a research proposal for testing a hypothesis that has emerged from his/her semester-long study of his/her organism. Students receive informal feedback from their peers at each stage of the project, which fosters communication and interest throughout the semester. Furthermore, the graduate student teaching assistant (referred to as ''TA-mentor'' in our course) monitors students' progress and provides formal feedback across the semester.

One additional goal of ''the organism'' exercise is to actively involve students in reading and interpreting the scientific literature, activities that are completely new to most students entering an introductory biology course. As students progress through the exercise they learn how to navigate the library, starting first by using general references and secondary literature, then moving to primary literature. The level of library research required increases as students progress through the exercise. For example, students use general references to identify their organism and ask initial questions about their organism. As students develop their own hypotheses, they use the primary literature to investigate previous research in their areas of interest.

The exercise has four main components (1) choosing organisms, (2) asking questions, (3) developing hypotheses, and (4) delivering an oral research proposal. Each stage of the exercise builds on previous work, and by the end of the semester students understand what it takes to design a research project. Students may focus their investigations at any level of biological organization, not just the organismal level; thus students have opportunities to identify and develop their own interests in the context of ''the organism'' project.

The Exercise

Choosing Organisms

During the first week of the semester, in seminar, we introduce students to the organism project. Our course consists of three main components: lecture, laboratory section and seminar section. Each section is composed of 12 students and one ''TA-mentor,'' with the same group of students meeting together for lab and seminar. Small sections led by a single TA-mentor allow us to have small-group learning experiences embedded within a larger, 240-person introductory course. In addition to learning content in lecture and performing experiments in laboratory, students have an additional forum in seminar to discuss biological material from new perspectives.

Table 1. Timetable and progression of organism project throughout semester.

TIMING	*ACTIVITY*
Week 1	• Introduction to organism project • Students choose organism
Week 3	• Identify organism using secondary literature • Ask questions about organism • Discuss levels of organization in biology
Week 7	• Propose testable hypothesis • Identify two primary references pertaining to hypothesis • Begin developing tests for hypotheses
Week 13	• Oral presentation on organism with outline of proposed test for hypothesis and expected results

The seminar section meets once a week for an hour and provides opportunities to engage students in active, inquiry-based learning.

We present students with a list of genera and each student chooses one genus from the list. The list of organisms consists of approximately 40 genera from four kingdoms (see Table 2 for examples). This list was compiled and checked using Biological Abstracts, Medline and Agricola to confirm that each genus had sufficient past research conducted on it to introduce students to a wide variety of biological approaches. We avoided organisms for which the literature was hard to follow for one reason or another. For example, we did not include the firefly genus *Photuris* because luciferase, originally derived from fireflies, is commonly used as a photodetection assay in a wide variety of molecular investigations that are unrelated to the genus *Photuris*. In addition, we avoided easily recognized genera such as *Canis* or *Gorilla* to prevent students from vying for a subset of charismatic, well-known organisms.

Once a genus has been chosen from the list, it is no longer available to anyone else in that section. Thus, each student in a 12-person section has a different organism, but there are frequently several students studying the same organism in our 240-person course. We encourage students to seek out these other students and share information they have gathered. After choosing a genus, students are given the taxonomic hierarchy for their organism, but not its common name [a complete list of organism taxonomies used in this exercise is available from WJH]. As part of their first assignment, students simply have to figure out what kind of organism they have chosen, using taxonomic resources available in the library.

To aid students in identifying their organism as part of their initial library search, we provide students with a list of useful, general taxonomically oriented references. For example, a student with *Strongylocentrotus* as her organism might first look in an invertebrate zoology resource text (e.g. Ruppert & Barnes

Table 2. Representative sample taxonomic hierarchies that students receive after choosing a genus from the organism list. Each of these representatives appears as an example in the accompanying text. The complete list (available from WJH) includes taxa from four kingdoms (Animalia, Fungi, Plantae, Protista).

Kingdom Plantae Division Anthophyta Class Magnoliopsida Order Sapindales Family Aceraceae Genus *Acer*	Kingdom Plantae Division Anthophyta Class Magnoliopsida Order Fagales Family Fagaceae Genus *Quercus*
Kingdom Animalia Phylum Mollusca Class Gastropoda Subclass Opisthobranchia Order Anaspidea Family Aplysiidae Genus *Aplysia*	Kingdom Plantae Division Anthophyta Class Magnoliopsida Order Caryophyllales Family Caryophyllaceae Genus *Silene*
Kingdom Animalia Phylum Chordata Class Amphibia Order Caudata Family Plethodontidae Genus *Plethodon*	Kingdom Animalia Phylum Echinodermata Class Echinoidea Order Echinoida Family Strongylocentrotidae Genus *Strongylocentrotus*

1994) if she recognized that echinoderms were marine invertebrates. If, however, with the student only recognizes that *Strongylocentrotus* is an animal, then she could start her search with a more general reference (e.g. Grzimek 1972). This initial search for an organism's identity increases student ownership in the project. In addition, students looking through the reference section of the library tend to help each other during this initial phase of the exercise and help foster cooperation in seminar groups; both of these interactions stimulate interest in the project.

After identifying their organism at the generic level, students choose a focal species within the genus they selected on which to concentrate the rest of their investigations. Although students have a focal organism, we make it clear that their exploration need not be limited to the organismal level of biology. Instead, we encourage students to investigate their organism at any level of biological organization they find interesting (from molecules to ecosystems). Allowing students the freedom to choose their own topic to investigate promotes general interest in biology and it also encourages students to identify their own specific interests.

Asking Questions About Organisms

During the third week of the semester students introduce their organism to the rest of their seminar section and present two or three questions they have developed from their initial readings. We find students' questions vary from being fairly simple (e.g. ''What does the sea slug, *Aplysia,* eat?'') to relatively advanced (e.g. ''How does *Aplysia* learn to avoid predators?''). This discussion has three goals. First, it gives students the opportunity to identify links among different organisms within each section.

For example, one organism may be the prey for another, or a number of organisms may occupy the same trophic level within an ecosystem. Students enjoy discovering connections among organisms and additional spontaneous discussions often evolve from these discoveries.

A second goal of this seminar exercise is to help students recognize different levels of biological organization and to gain some appreciation for how interesting questions can be used to investigate each level. The questions within a single section usually address multiple levels of biological organization ranging from cellular questions (e.g. ''How do the muscles of the rat snake, *Elaphe*, contract and how strong are they?''), to metabolic questions (e.g. ''What happens to the vital systems during hibernation in the rat snake, *Elaphe*?''), to questions about locomotion (e.g. ''How does the sea urchin, *Strongylocentrotus*, move using tube feet and spines?''), to questions about reproduction and speciation (e.g. ''What are the ecological conditions that have made the species of maple trees differ so greatly in Asia and the Americas?''). During this discussion we emphasize multiple levels of biological organization as one way to avoid biasing students from just asking questions on the organismal level. As students identify their own interests we help them find ways to pursue these interests as they develop hypotheses and experimental tests.

A final goal of this seminar session is to reinforce the role of hypotheses and hypothesis testing in biology. After students pose general questions about their organisms we ask them how they might go about answering some of their questions. Earlier in the semester (in two different seminar exercises) students already will have discussed scientific methods, how hypotheses lead to testable predictions, and how experiments can be designed to test those predictions. We re-introduce the role of hypotheses in biology during this session as a prelude to the students' next assignment in which they consult the primary literature and develop their own hypotheses about their organism.

Developing Hypotheses

By the seventh week of the semester the focus of the project shifts from the organisms themselves to hypothesis generation. Students with similar initial questions end up developing very different hypotheses. For example, questions about how an organism eats have evolved into hypotheses focused on foraging behavior, prey capture, digestion, and metabolic pathways of ingested food. As students identify their own interests they need additional information from the primary literature in order to make substantial progress on their hypotheses.

When using library resources most students turn to Biological Abstracts or Medline to identify primary references. By performing keyword searches combining terms to include topics of interest and their organism name, students usually locate multiple relevant references. For example, a student interested in salamander nesting behavior performed a search using the following terms: ''mating,'' ''nest,'' ''*Plethodon*'' and ''nesting behavior.'' From this search she identified eight sources that she thought would be useful in developing her own hypothesis about salamander nesting behavior. Students supplement computer searches with additional referencing from papers they identify from initial searches, so that their keyword search is often the beginning of their investigation into their hypotheses.

Discussion of hypotheses during the seminar session works in the following way: Meeting in pairs, each student presents her/his hypothesis to another student. Meeting one-on-one in this way promotes student interaction and provides an opportunity to for students to give specific feedback on each other's hypotheses. To facilitate individual explanations we provide each listener with questions to ask and record the answers during discussion. Half-way through the seminar we reconvene and each student presents his/her partner's hypothesis to the group as a whole. This format emphasizes the need for students to be clear and precise in what they are trying to say, and provides informal feedback to each student on his/her hypothesis.

During this session we also discuss different approaches biologists use to test hypotheses. Most students already are familiar with the idea of experimentation, in which one or more variables are manipulated and compared to a control. Students are less familiar with the use of observational tests, modeling, and the phylogenetic comparative method as alternative approaches to investigating biology. In laboratory we use each of these methods to investigate biological phenomena. For example, students create their own phylogenetic hypotheses based on skull morphologies in primates and compare their trees with published hypotheses. By the end of the semester students have had laboratory experience working with many investigative methods and often use a combination of approaches to address their hypotheses.

Oral Research Proposals

During the last week of the semester students deliver 10- to 12-minute oral presentations in which they outline the research proposals they have developed to test hypotheses about their organisms. The hypothesis and how to test it are the main themes of the presentations. Students introduce their topics with information sufficient to give the audience a general background to the problem and previous research in their area of interest. Students describe their hypotheses in detail, including alternative hypotheses, and how the original hypotheses may be broken up into subsidiary hypotheses. Students also explain their research plans, experimental designs, and how their proposed tests explicitly relate to their hypotheses. We encourage students to address assumptions that they make in their experimental designs. Finally, we ask students to discuss the predicted results of their proposed research and to interpret these results in light of their original hypotheses.

For many students, this is the first oral presentation they have delivered to their peers, and the quality of student talks varies greatly, depending on how comfortable they feel about public speaking. Thus, TA-mentors emphasize clarity, knowledge and appropriateness of a student's research proposal for testing their hypotheses, while de-emphasizing the importance of presentation mechanics (i.e. polish and audio-visuals). We ask students to prepare outlines of their talks and lists of references that not only make it easier for other students to follow along, but also provide the TA-mentor with an additional basis for evaluation that is independent of the delivery of the talks. Therefore, we have a mechanism to address how a student is thinking about the material even if that student has poor speaking skills.

Using the Organism Exercise

"The organism" exercise easily can be incorporated as an integrative theme running across the term in a wide range of biology courses. The exercise requires few supplemental materials other than access to library resources, thus it is not costly to implement. It provides opportunities for students to teach each other about biology, thereby increasing student interest and understanding (Trombulak 1995; Brewer & Ebert-May 1998; Lord 1998). In addition, the list of organisms can be tailored to fit the structure and content of particular courses. For example, an introductory zoology course might eliminate botanical organisms while expanding the list of zoological representatives.

Anecdotal evidence suggests that "the organism" exercise stimulates student interest in biology. Students who initially are not excited about their organism often identify and develop interesting hypotheses and research proposals if they can get beyond their early reluctance. One student, for instance, struggled with *Quercus* for much of the semester until she realized that she was interested in community-level interactions among species. Her final presentation, about which she was extremely enthusiastic, focused on hypotheses of seed dispersal mechanisms by acorn-eating squirrels. A key to success with many students is to find ways of helping them identify their interests, and then connecting these interests with some aspect of their organisms. One of the strongest measures of success is that former students often contact us to tell us that they saw "their" organisms. Often they observe their organisms while travelling or while at home and they are excited to be able to share background information and natural history about their organisms with their families and friends. For example one student wrote us that "meeting" her organism, *Gigartina*, while snorkeling was like discovering a friend in a land of strangers.

Finally, students self-report on course evaluations that the organism project facilitated their learning, the oral presentation of their project facilitated their learning, and the project increased their understanding of scientific methods (Figure 1). We measured student responses over three semesters. Our evaluation scale included the following six categories : (1) strongly disagree, (2) disagree, (3) somewhat disagree, (4) somewhat agree, (5) agree and (6) strongly agree. Most students felt that the project facilitated their learning (mean = 4.0, n = 456). Most students believed that their oral presentation facilitated their learning (mean = 3.9, n = 454). Finally, students felt that their understanding of the scientific method was increased by this project (mean = 4.0, n = 458). While these results suggest that the organism exercise stimulates learning, it is important to recognize that student perception of learning may not reflect actual learning. In order to address how student perception relates to performance we asked students to report their satisfaction of (1) the content and (2) the organization of their oral presentation. We measured student satisfaction in one semester after all students had given their presentation but before their presentation grade was returned; this controlled for the possibility that presentation grade could influence student satisfaction. Using linear regression we evaluated whether satisfaction could predict the grade students received on their presentation. We find that student satisfaction of the content is positively related with presentation grade ($F = 14.69$, $p = 0.19 * 10^{-3}$, $R^2 = 0.09$, $n = 144$). In addition, student satisfaction of presentation organization was positively related with presentation grade ($F = 12.21$, $p = 0.63 * 10^{-3}$, $R^2 = 0.08$, $n = 144$). Students, therefore, have some understanding of how content and organization relate to their performance. Thus, by extension, it seems reasonable to conclude that student responses of the impact of the project on their learning are likely to reflect actual learning.

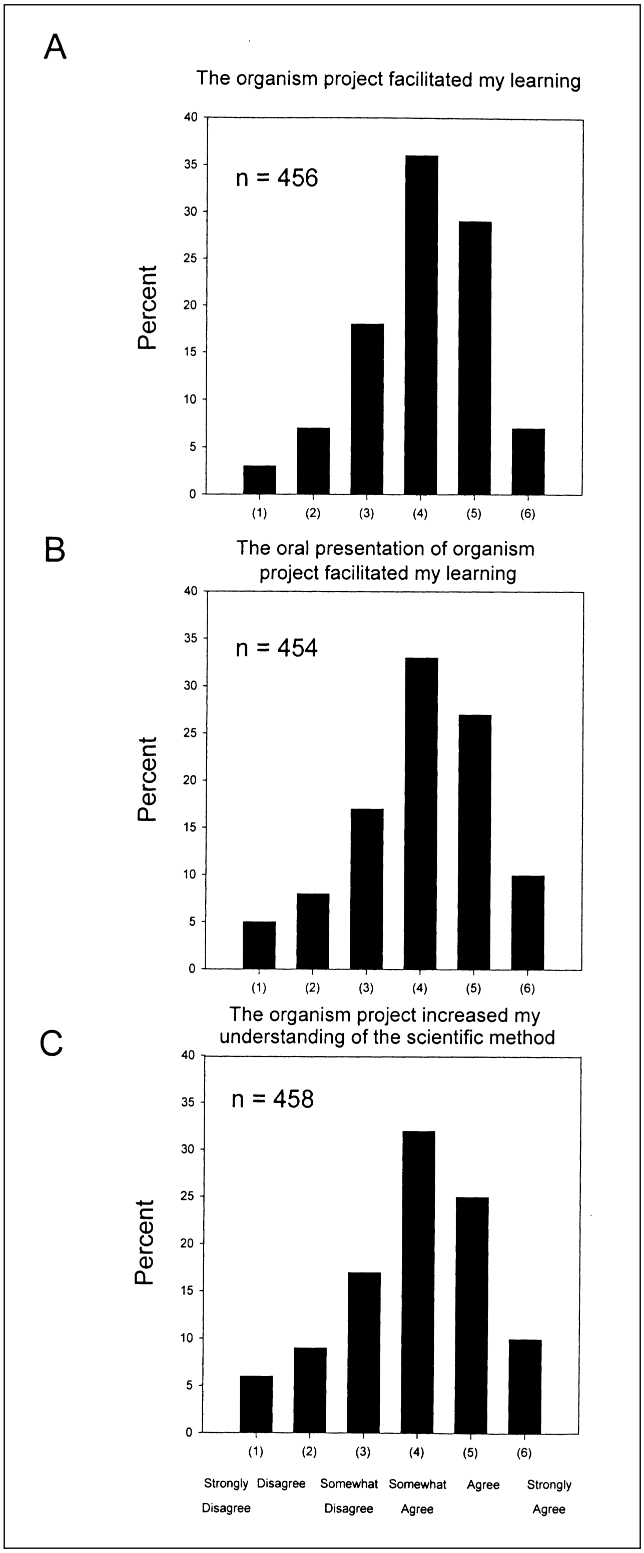

Figure 1. Student assessment of the organism exercise. Summary of student evaluations from fall 1998, spring 1999 and fall 1999 semesters. Students responded on a 1 to 6 scale to the following statements: **A.** The organism project facilitated my learning (mean response = 4.0). **B.** The oral presentation of the organism project facilitated my learning (mean response = 3.9). **C.** The organism project increased my understanding of the scientific method (mean response = 4.0).

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